Fermilab

http://www.fnal.gov

HINS Beam Optics Topics

Contents: A Broad Band Chopper for the CW linac

Optics optimization for energy spread measurement

Eliana GIANFELICE

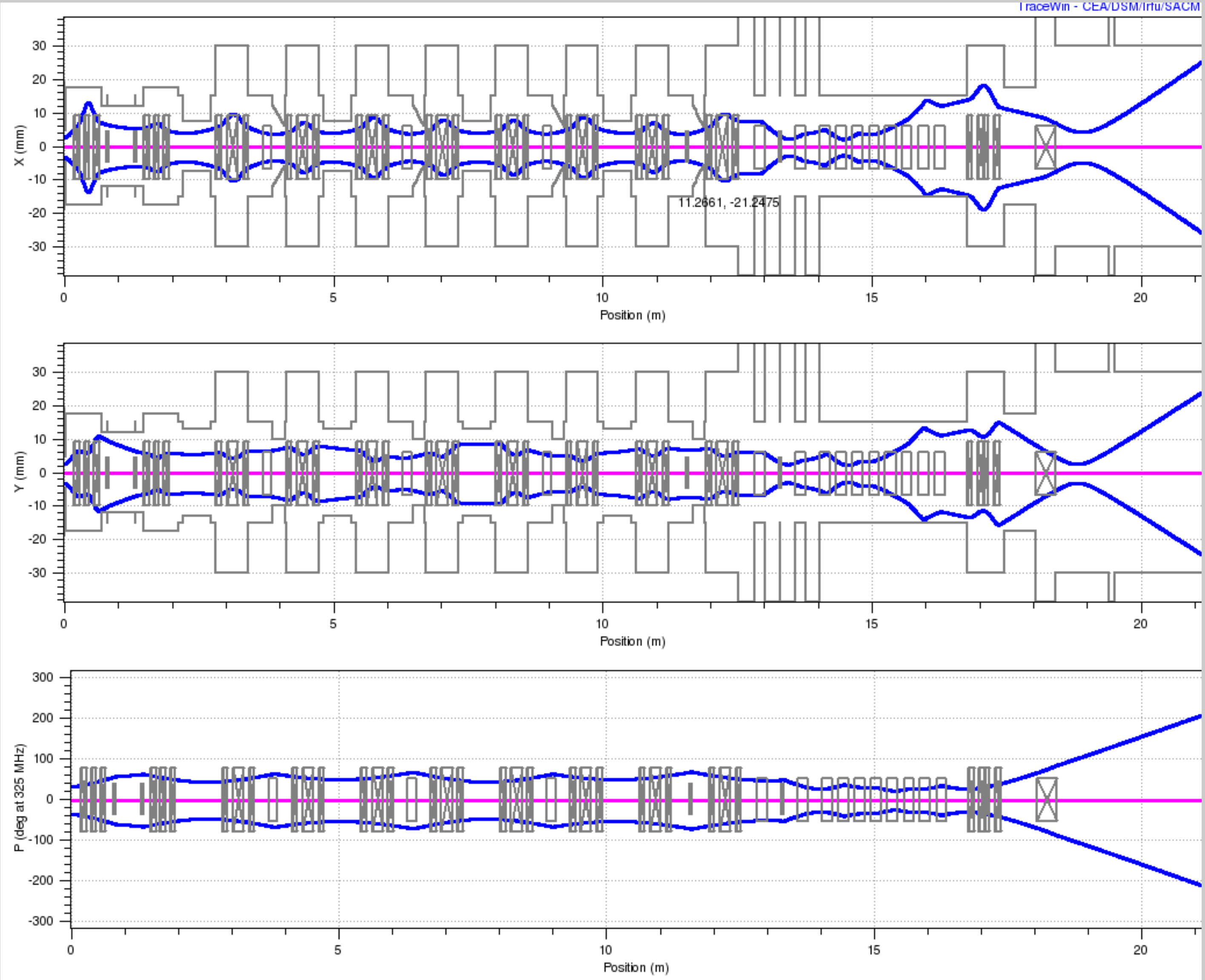
eliana@fnal.gov

Beam line

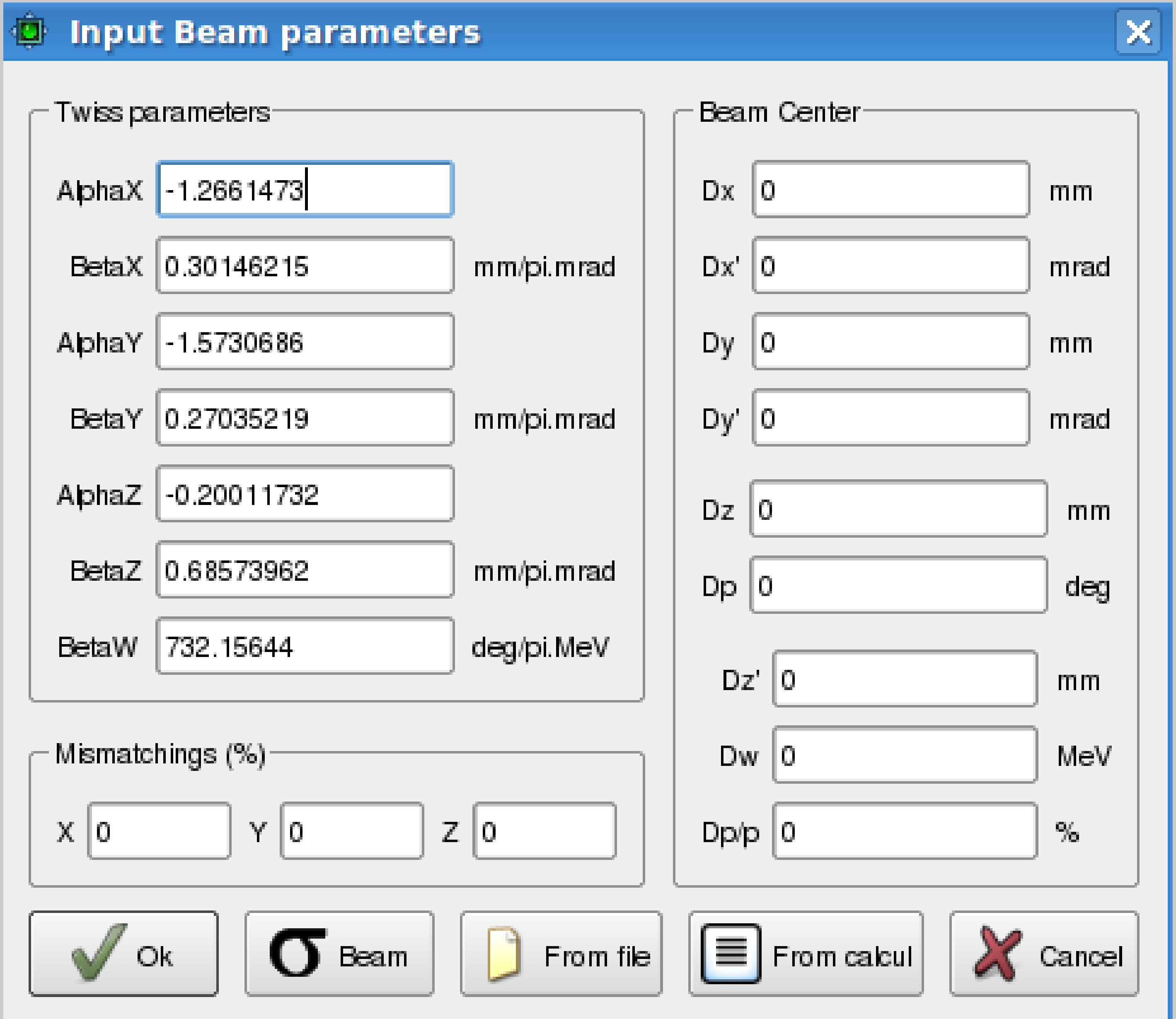
Optics (from RFQ):

- 2 triplets and two bunchers matching RFQ to chopper
- chopper
- 2RT solenoids and one gap matching chopper to the SSR0 section
- 4 SSR0 cavities and 4 RT solenoids
- a large aperture triplet and bending magnet have been added at the end of the beam line for energy spread measurement

Beam 3σ envelopes



Starting conditions at RFQ exit (small spurious (?) offsets zeroed)



Broad Band Chopper

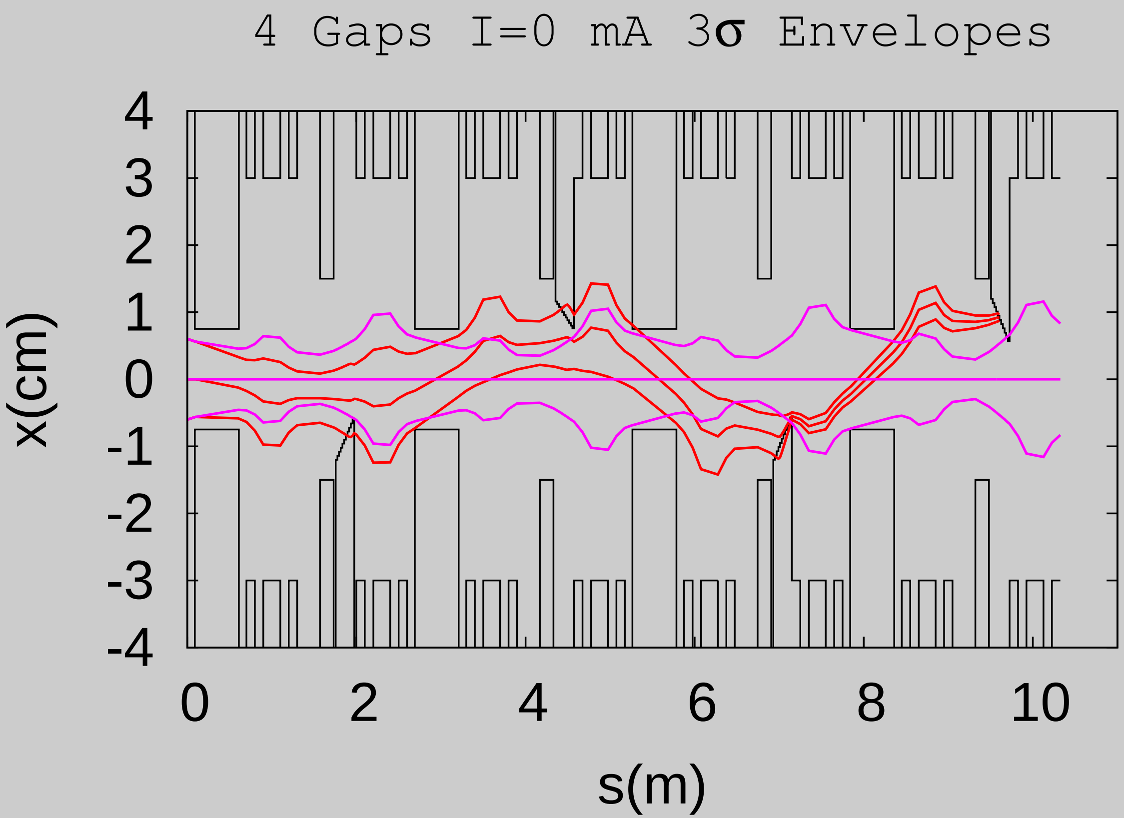
The chopper optics (from V. Lebedev) consists of 8 triplets interleaved by 4 kickers and 4 bunchers.

Chopper kickers:

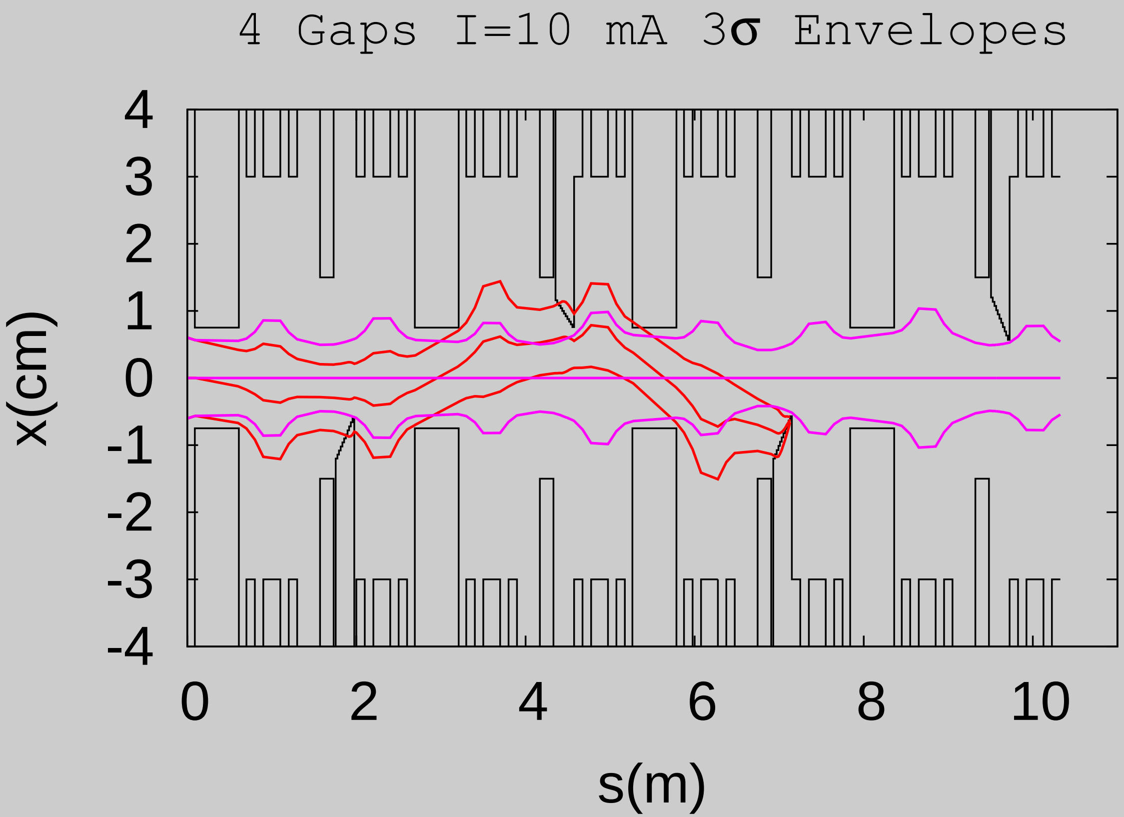
- 4 Kickers each 0.5 m long with a 1.5 cm gap
- each provides 5 mrad kick, assuming $\simeq$ 748 V feasible

With $\boldsymbol{\theta_1}=\boldsymbol{\theta_3}=-\boldsymbol{\theta_2}=-\boldsymbol{\theta_4}=$ 5 mrad the kicked beam can be intercepted by 4 collimators.

TRACK



TRACK



Losses have been studied by N. Perunov in the “nominal” configuration and found acceptable.

Issues

- kicker strength
- effect of misalignments, not yet studied

Energy spread measurement

The beam size includes two terms

$$\boldsymbol{\sigma = \sqrt{\epsilon\beta + D^2 \left(\frac{\Delta p}{p}\right)^2}}$$

If a horizontal dipole is introduced downstream the beam line for creating horizontal dispersion the energy spread may be measured from the beam size.

In general:

- *sector* magnet is more efficient than a rectangular one
- stronger the dipole, larger the dispersion

The best location for the Wire Scanner should be a location with maximum $\boldsymbol{D_x^2/\beta_x}$: the optics should be designed so that $\boldsymbol{\beta_x}$ has a minimum no too close to the dipole allowing $\boldsymbol{D_x}$ to grow.

Problems encountered with TraceWin:

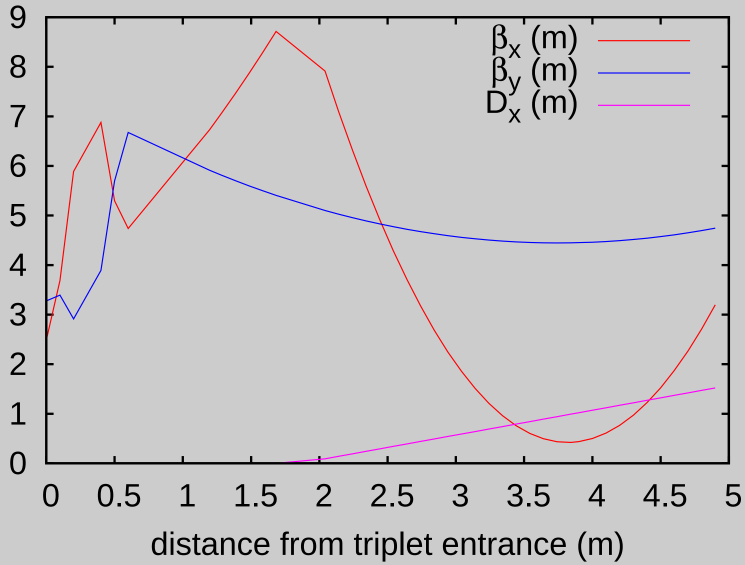
- TraceWin computes the "correct" $\boldsymbol{\beta_x}$ only if $\boldsymbol{\Delta p/p}$ is made artificially small
- The Twiss values for a *rectangular* magnet are *not* in agreement with MAD.

In this computation the wire scanner has been located at 1.86 m from dipole exit.

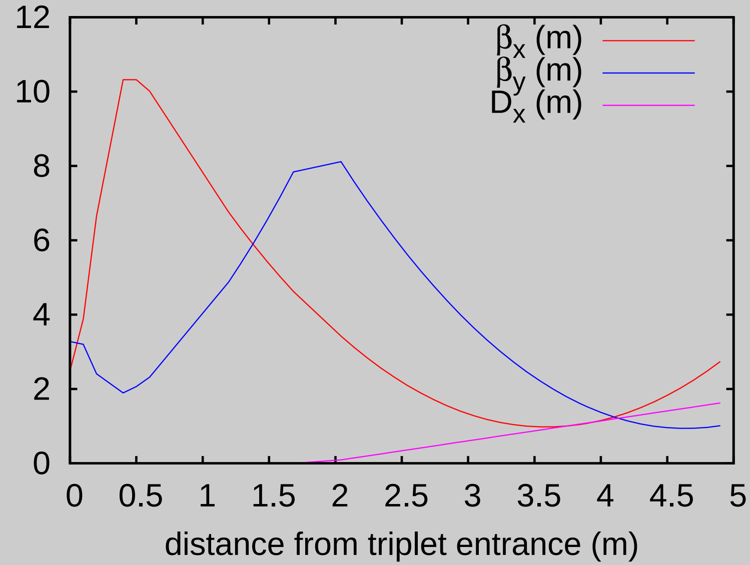
The strength of the last triplet is optimized (with MAD-X) so to maximize $\boldsymbol{\sigma^2_{x,p}/\sigma^2_{x,\beta}}$ keeping $\hat{\boldsymbol{\beta}}_{\boldsymbol{x}}$ and $\hat{\boldsymbol{\beta}}_{\boldsymbol{y}}$ below a given value, $\hat{\boldsymbol{\beta}}$.

For instance, we fix $\boldsymbol{\phi_b}$=30 degrees and $\boldsymbol{B}$=0.340 T ($\boldsymbol{\rho}$=0.684 m, $\boldsymbol{\ell_{arc}}$=0.358 m) and ask for $\hat{\boldsymbol{\beta}}_{\boldsymbol{x}}=\hat{\boldsymbol{\beta}}_{\boldsymbol{y}} < 9$ m.

Sector magnet: $\boldsymbol{\sigma^2_{x,p}/\sigma^2_{x,\beta}} \simeq 8$



Rectangular magnet: $\boldsymbol{\sigma^2_{x,p}/\sigma^2_{x,\beta}} \simeq 3$



Wire Scanner is at 3.9 m

Without space charge, at the WS location is $(\Delta p/p)_{rms}$=3.2×10^{-3}, $\beta_x = 0.437$ m and $D_x = 1.020$ m. Thus (with $\beta\gamma$=0.079)

$$\sigma^2_{x,\beta} \equiv \beta_x \epsilon_x = 0.437 \times \frac{0.25}{0.079} \times 10^{-6} = 1.383 \times 10^{-6} \text{ m}^2$$

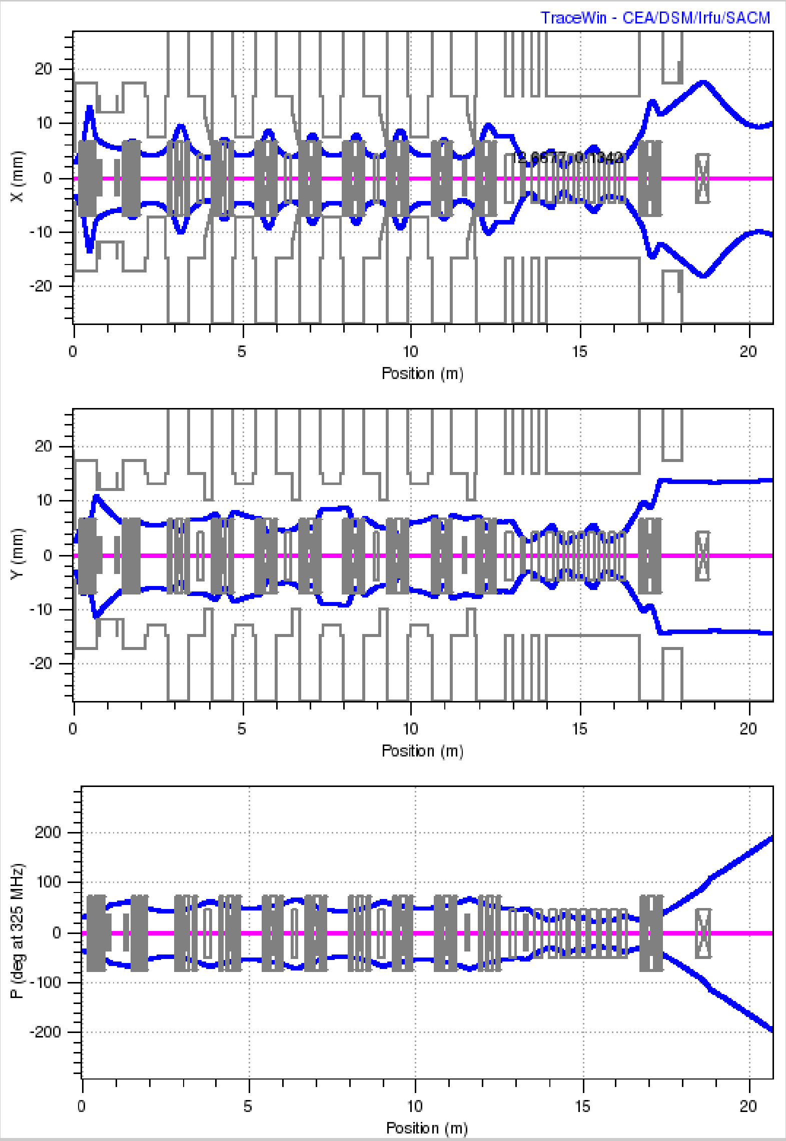
$$\sigma^2_{x,p} \equiv \left[D_x \frac{\Delta p}{p} \right]^2 = \left[1.020 \times 3.2 \times 10^{-3}\right]^2 = 10.65 \times 10^{-6} \text{ m}^2$$

Ignoring the $\sigma_{x,\beta}$ contribution to the total beam size and computing $\Delta p/p$=σ_x^{tot}/D_x we get 3.4×10^{-3} with an error of 6%.

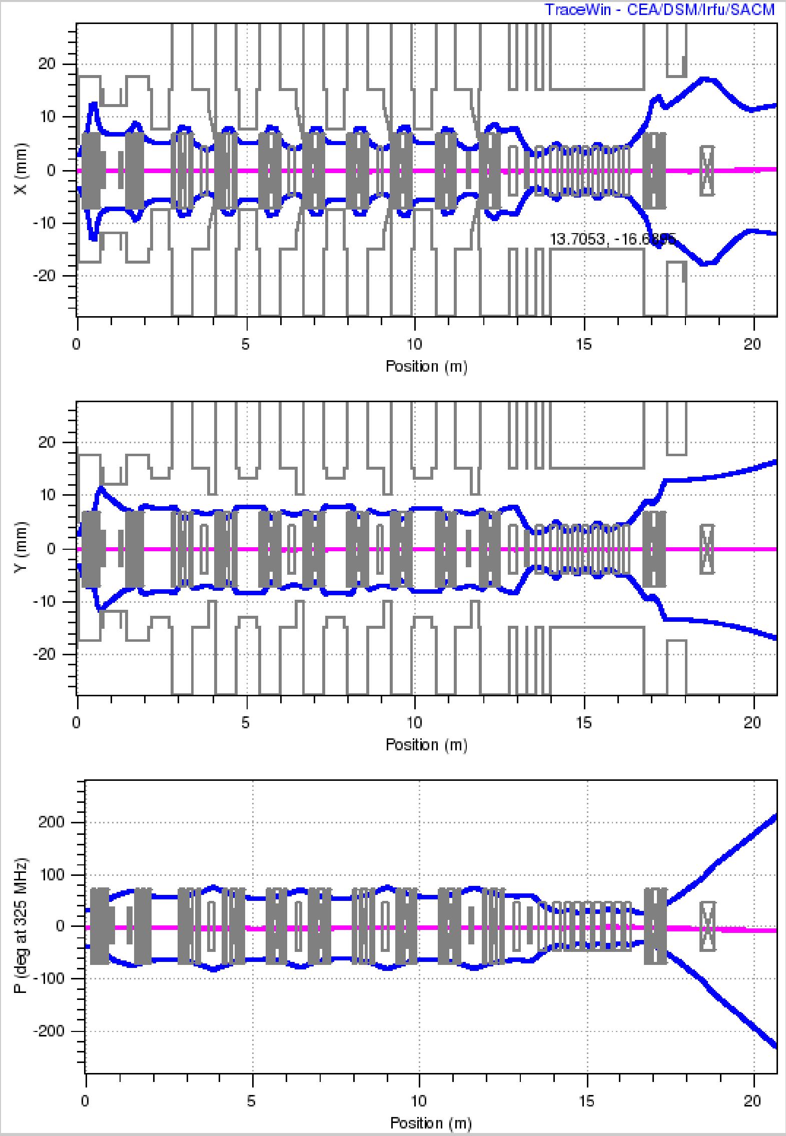
We can insert a slit upstream the dipole to decrease the horizontal emittance and improve the precision.

TraceWin

I=0 mA



I=10 mA



Extra slides

TraceWin vs. MADX.

For instance, for ϕ_b=30 degrees rectangular bend:

	ℓ_{arc}	β_x	α_x	β_y	α_y	D_x
MADX	0.358299	1.117067	-0.342150	0.867466	0.318003	0.092
TraceWin	0.3582986	0.9534	-0.1608	0.9398	-0.2161	0.092
TraceWin(*)	0.3582986	1.2272	-0.2427	1.0578	-0.5182	0.092

(*) Reducing longitudinal emittance by a factor 1e-3.

Estonishing the disagreement in the vertical plane.

It is convenient

- strong bend to get larger dispersion
- *sector* magnet for focusing downstream at the Wire Scanner

Dispersion downstream dipole

$$D = D_0 + D'_0 s$$

with (sector magnet)

$$D_0 = \rho(1 - \cos\phi_b) \quad \text{and} \quad D'_0 = \sin\phi_b$$

(D_0 and D'_0 being the values at the exit of the dipole).
It is convenient therefore a large ϕ_b and a large ρ.
But the focusing is $M_{21} = -\sin\phi_b/\rho$: the bending radius is determined by a balance between focusing and dispersion.

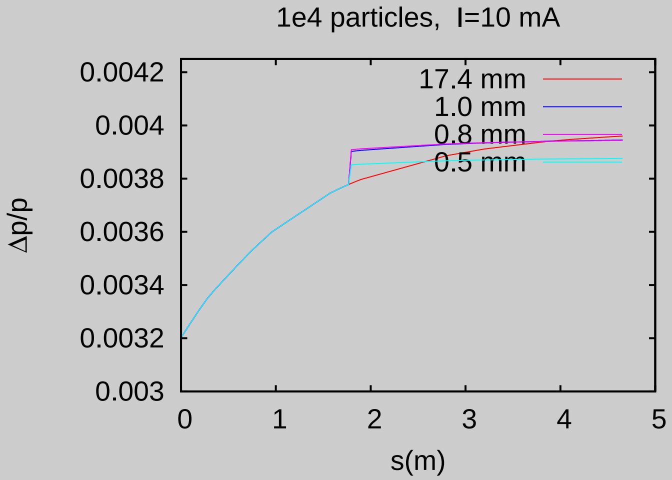
Error vs slit gap

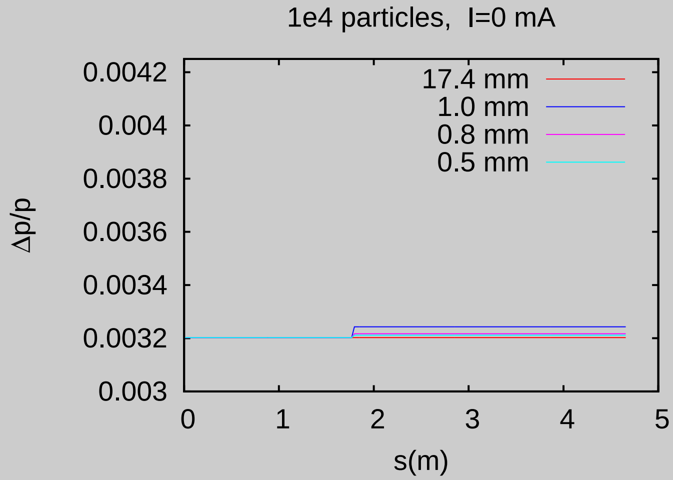
Check slit effect through tracking: $2\times\mathbf{10^4}$ particles, starting conditions extracted from a 6D ellipsoid and tracked from RFQ to slit entrance with $\boldsymbol{I} = 10$ mA. The new distribution is tracked through the slit to the wire scanner position. The slit is 1 cm long.[a]

$\boldsymbol{I}$ (mA)	width ($\boldsymbol{\mu}$m)	losses (%)	$\boldsymbol{\epsilon_x^N}$ (mm mrad)	$\boldsymbol{\sigma_x}$ (mm)	$\boldsymbol{(\Delta p/p)_{rms}}$ (%)	$\boldsymbol{\sigma_x/D_x}$ (%)	error (%)
10	17400×2	0	0.619	0.275	0.342	0.443	29
0	250×2	95	0.009	2.55	0.378	0.411	9
10	250×2	95	0.009	2.58	0.371	0.415	12
0	700×2	87	0.026	2.59	0.378	0.418	10
10	700×2	87	0.026	2.69	0.366	0.433	12

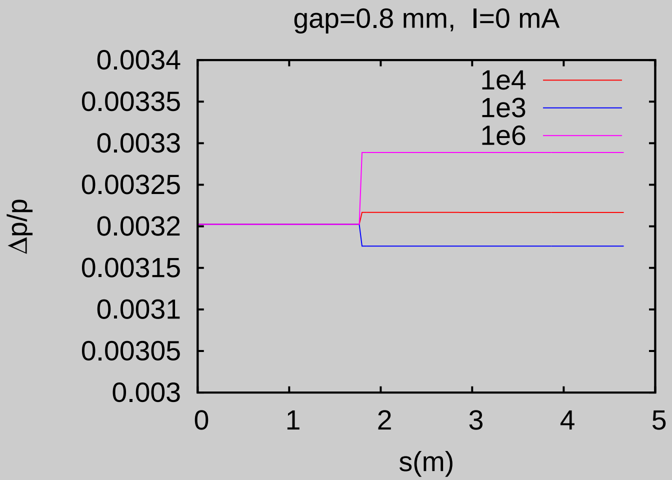
There is an *intrinsic* error which seems not strongly related to space charge.

[a] nb: results for a different optics!





Slit aperture changes $\boldsymbol{\Delta p/p}$ (?). It happens only by tracking. Statistics?



It does not seem the case...